GOES VW Workshop Summary

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Acknowledgments:

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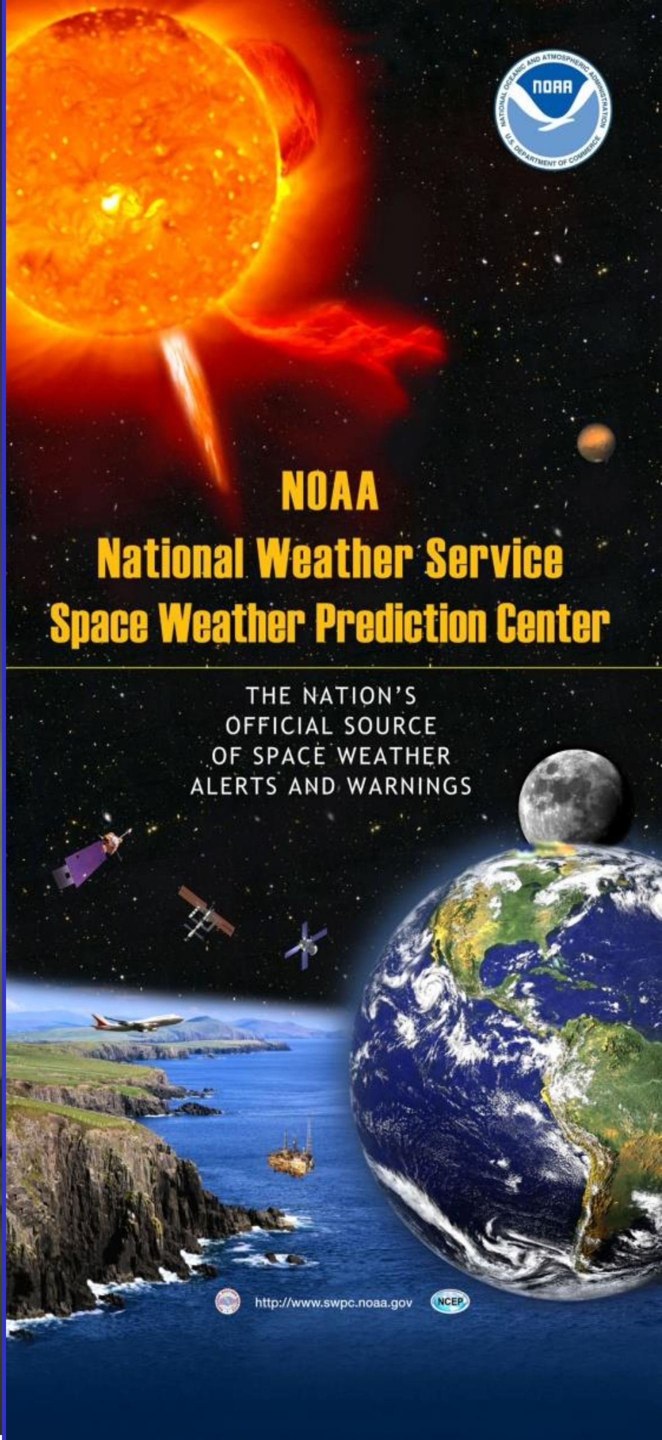
Space Weather Workshop

April 14, 2015



Geosynchronous Orbit
A Little History
(incomplete, but hopefully accurate)

- 1929 Austrian engineer Hermann Noordung suggests location in orbit around Earth that is synchronous with Earth's rotation
- 1945 Arthur C. Clarke idea for using 3 satellites, equally space around the equator, for global communications
- 1961 Hughes Aircraft Company wins $ 4 million contract from NASA GSFC and the US DoD to build 3 synchronous communications satellites
- 1963 Hughes Syncom 2 might be considered the first successful geosynchronous satellite used for communications
- 1966 NASA launched the first Applications Technology Satellite (ATS-1), including spin scan camera pioneering weather observations from space
- 1974 and 1975 NASA's SMS-1 and -2 for meteorology
- 1975 GOES-1 the first operational meteorological satellite

GOES Next (GOES VW) Workshop

April 13, 2015

Background

- Since 1975, beginning with GOES-1, and even before with the NASA Synchronous Meteorological Satellites (SMS), space weather monitoring has been included on the NOAA Geosynchronous Operational Environmental Satellites.

- In March 2016, the first of the GOES-R Series (R,S, T, and U), will be launched to extend GOES space weather observations into the 2030's.

- GOES-R will monitor the sun, as well as in-situ measurements of energetic particles and Earth's magnetic field to provide continuity of observations as well as some new capabilities for space weather forecasting and specification.

GOES Next (GOES VW) Workshop

April 13, 2015

Goals

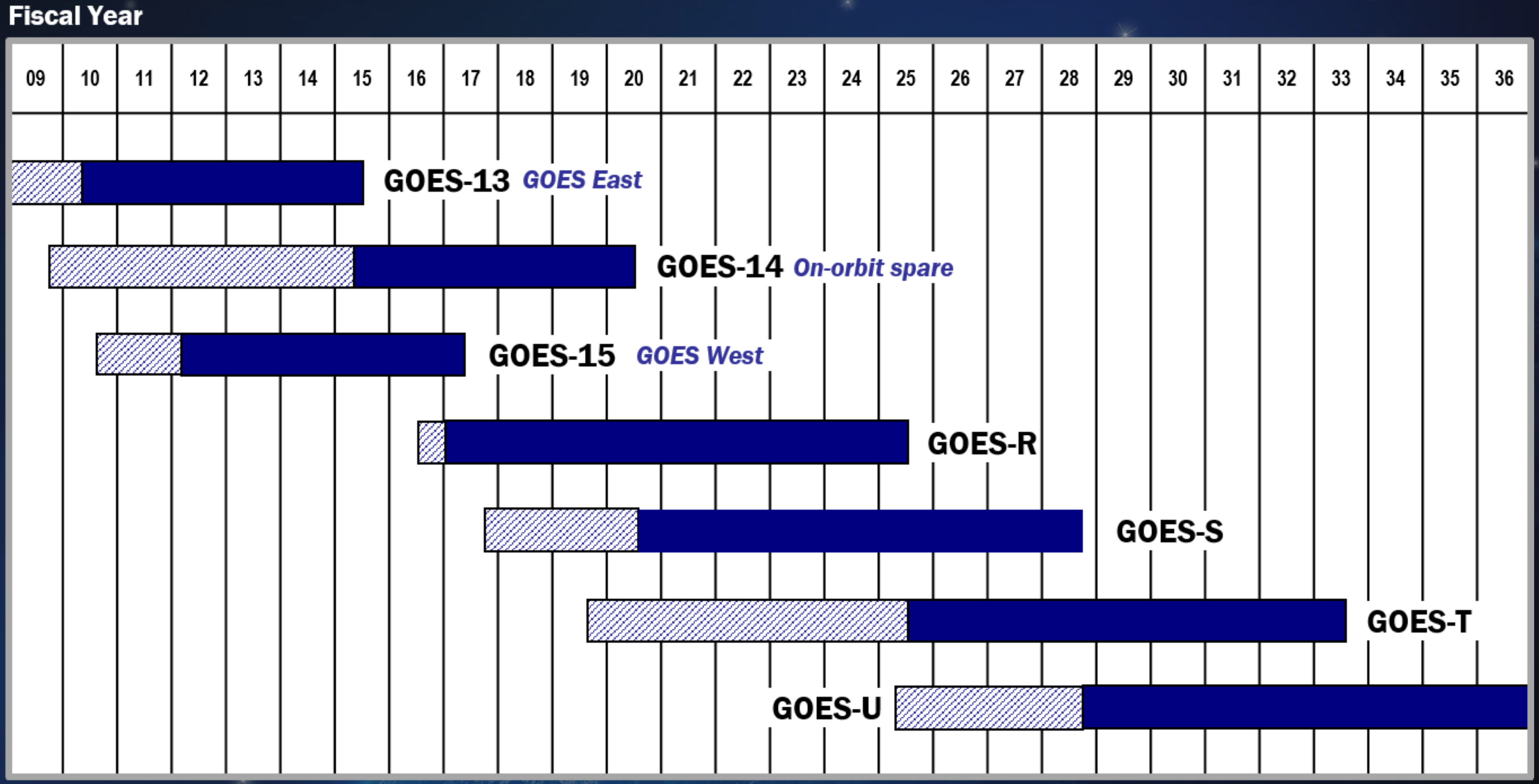
- To prepare for the follow-on to GOES-R (GOES Next beginning in the 2020’s), SWPC is initiating a process to assess and validate space weather observation requirements based on needs of forecasters and customers of space weather products and services.
- The goal of yesterday’s workshop was to review current space weather observation requirements, capabilities and products, and initiate a discussion to refine requirements, to gather suggestions for changes or modifications, and to identify gaps in observations.
- This is only the first of more opportunities to provide input on requirements as well as technologies and instrument capabilities needed to meet requirements.

GOES VW Workshop
April 13, 2015
Meeting Agenda

Requirements for the Next Generation Geosynchronous Space Weather Observations

- Introduction and Requirements Process
- GOES VW: Schedule and Process
- Parallel Breakout 1: Solar
  - X-ray Sensor (XRS), Extreme Ultraviolet Sensor (EUVS), Solar Imaging (including Solar Ultraviolet Imager (SUVI)), Forecaster perspective
- Parallel Breakout 2: In-situ
  - Magnetometer (Mag), Space Environment In-Situ Suite (SEISS) Energetic Particles, Forecaster Perspective
- Plenary Wrap Up (including presentation on GOLD)

Continuity of GOES Operational Satellite Program



GOES: Geostationary Operational Environmental Satellite

On-orbit storage

Operational

Goodman

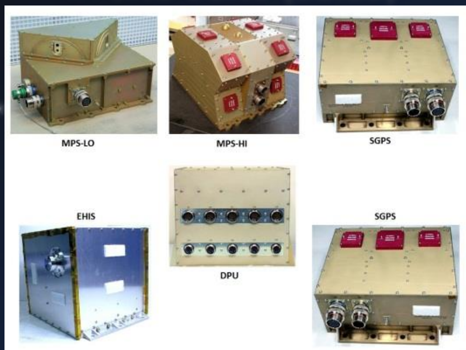
Goodman Summary

GOES-R Series Follow-on

- In developing the observations requirements, what science measurements are required by forecasters and why
- What is the best vantage point- Geo, Leo, L1, other, for each in a holistic/comprehensive constellation
- Determine what science and measurements are best served from a GEO orbit. This information would be helpful to NOAA in determining what the multi-platform, multi-senor optimal integrated observing system for space weather forecasting should move towards.

Space Weather Instruments

Space Environment In Situ Suite (SEISS)

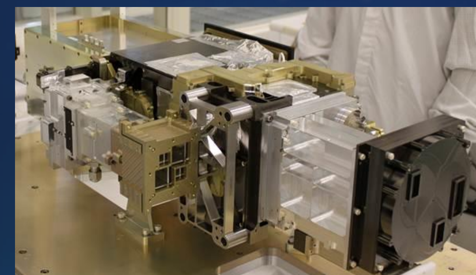


- Array of energetic particle sensors that will monitor the proton, electron and heavy ion particle fluxes
- Assess radiation hazard to astronauts and satellites
- Warn of high flux events, mitigating damage to radio communications and navigation systems

Magnetometer

- Measures the magnitude and direction of the Earth's ambient magnetic field
- Provides map of the space environment that controls charged particle dynamics in the outer region of the magnetosphere
- Detection of magnetopause crossings, sudden storm commencements, substorms and model validation

Extreme Ultraviolet Sensor and X-ray Irradiance Sensor (EXIS)



- The X-Ray Sensor (XRS) monitors solar flares that can disrupt dayside communications and degrade navigational accuracy, affecting satellites, astronauts, and airline passengers
- Extreme Ultraviolet Sensor (EUVS) monitors solar variations that directly affect satellite drag/tracking and ionospheric changes, which impact communications and navigation operations.

Solar Ultra-Violet Imager (SUVI)

- Locates coronal holes, flares and coronal mass ejection source regions
- Continuously images the sun in 6 extreme ultraviolet wavelengths to characterize active region complexity
- Will provide an early warning of possible impacts to the Earth environment and enable better forecasting of potentially disruptive events

Modified from Goodman

Space Weather Scales

- **Three Categories**
  - **Geomagnetic Storms**

    (CMEs and CIRs)

NOAA Space Weather Scales

Category: Scale	Category: Descriptor	Effect (Duration of event will influence severity of effects)	Physical measure	Average Frequency (1 cycle = 11 years)
Geomagnetic Storms			Kp values* determined every 3 hours	Number of storm events when Kp level was met; (number of storm days)
G 5	Extreme	Power systems: widespread voltage control problems and protective system problems can occur, some grid systems may experience complete collapse or blackouts. Transformers may experience damage. Spacecraft operations: may experience extensive surface charging, problems with orientation, uplink/downlink and tracking satellites. Other systems: pipeline currents can reach hundreds of amps, HF (high frequency) radio propagation may be impossible in many areas for one to two days, satellite navigation may be degraded for days, low-frequency radio navigation can be out for hours, and aurora has been seen as low as Florida and southern Texas (typically 40° geomagnetic lat.)**.	Kp=9	4 per cycle (4 days per cycle)
G 4	Severe	Power systems: possible widespread voltage control problems and some protective systems will mistakenly trip out key assets from the grid. Spacecraft operations: may experience surface charging and tracking problems, corrections may be needed for orientation problems. Other systems: induced pipeline currents affect preventive measures, HF radio propagation sporadic, satellite navigation degraded for hours, low-frequency radio navigation disrupted, and aurora has been seen as low as Alabama and northern California (typically 45° geomagnetic lat.)**.	Kp=8, including a 9-	100 per cycle (60 days per cycle)
G 3	Strong	Power systems: voltage corrections may be required, false alarms triggered on some protection devices. Spacecraft operations: surface charging may occur on satellite components, drag may increase on low-Earth-orbit satellites, and corrections may be needed for orientation problems. Other systems: intermittent satellite navigation and low-frequency radio navigation problems may occur, HF radio may be intermittent, and aurora has been seen as low as Illinois and Oregon (typically 50° geomagnetic lat.)**.	Kp=7	200 per cycle (130 days per cycle)
G 2	Moderate	Power systems: high-latitude power systems may experience voltage alarms, long-duration storms may cause transformer damage. Spacecraft operations: corrective actions to orientation may be required by ground control; possible changes in drag affect orbit predictions. Other systems: HF radio propagation can fade at higher latitudes, and aurora has been seen as low as New York and Idaho (typically 55° geomagnetic lat.)**.	Kp=6	600 per cycle (360 days per cycle)
G 1	Minor	Power systems: weak power grid fluctuations can occur. Spacecraft operations: minor impact on satellite operations possible. Other systems: migratory animals are affected at this and higher levels; aurora is commonly visible at high latitudes (northern Michigan and Maine)**.	Kp=5	1700 per cycle (900 days per cycle)

* Based on this measure, but other physical measures are also considered.

** For specific locations around the globe, use geomagnetic latitude to determine likely sightings (see www.sec.noaa.gov/Aurora)

Solar Radiation Storms			Flux level of ≥ 10 MeV particles (ions)*	Number of events when flux level was met**
		Biological: unavoidable high radiation hazard to astronauts on EVA (extra-vehicular activity); high radiation exposure to passengers and crew in commercial jets at high latitudes (approximately 100 chest x-rays) is possible. Satellite operations: satellites may be rendered useless, memory impacts can cause loss of control, may cause	10^5	Fewer than 1 per cycle

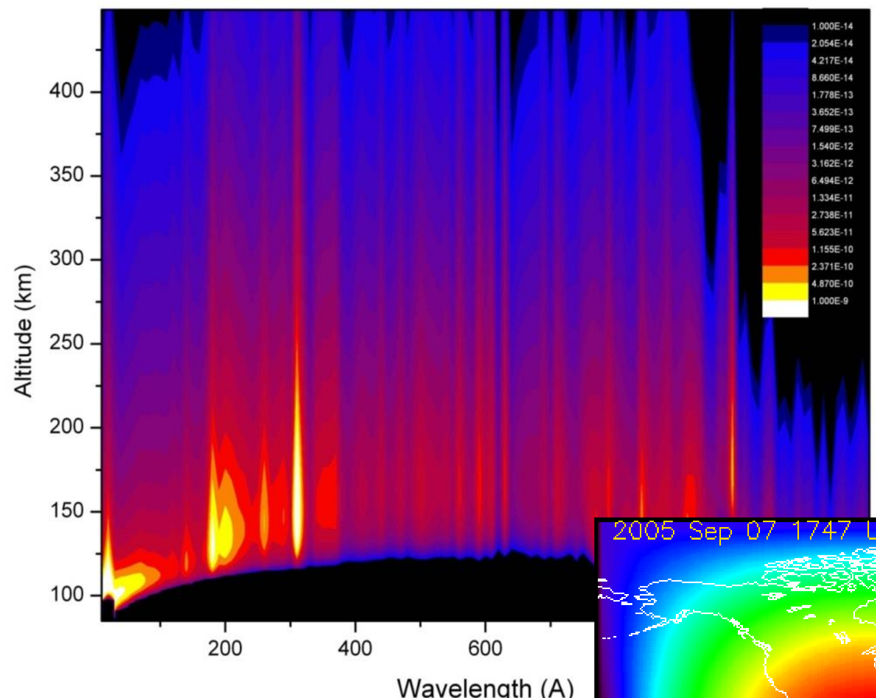
Geomagnetic Storms			Kp values* determined every 3 hours	Number of storm events when Kp level was met; (number of storm days)
G 5	Extreme	Power systems: widespread voltage control problems and protective system problems can occur, some grid systems may experience complete collapse or blackouts. Transformers may experience damage. Spacecraft operations: may experience extensive surface charging, problems with orientation, uplink/downlink and tracking satellites. Other systems: pipeline currents can reach hundreds of amps, HF (high frequency) radio propagation may be impossible in many areas for one to two days, satellite navigation may be degraded for days, low-frequency radio navigation can be out for hours, and aurora has been seen as low as Florida and southern Texas (typically 40° geomagnetic lat.)**.	Kp=9	4 per cycle (4 days per cycle)

		on the sunlit side of the Earth for many hours, causing loss in positioning. Increased satellite navigation errors in positioning for several hours on the sunlit side of Earth, which may spread into the night side.		
R 4	Severe	HF Radio: HF radio communication blackout on most of the sunlit side of Earth for one to two hours. HF radio contact lost during this time. Navigation: Outages of low-frequency navigation signals cause increased error in positioning for one to two hours. Minor disruptions of satellite navigation possible on the sunlit side of Earth.	X10 (10^{-3})	8 per cycle (8 days per cycle)
R 3	Strong	HF Radio: Wide area blackout of HF radio communication, loss of radio contact for about an hour on sunlit side of Earth. Navigation: Low-frequency navigation signals degraded for about an hour.	X1 (10^{-4})	175 per cycle (140 days per cycle)
R 2	Moderate	HF Radio: Limited blackout of HF radio communication on sunlit side, loss of radio contact for tens of minutes. Navigation: Degradation of low-frequency navigation signals for tens of minutes.	M5 ($5x10^{-5}$)	350 per cycle (300 days per cycle)
R 1	Minor	HF Radio: Weak or minor degradation of HF radio communication on sunlit side, occasional loss of radio contact. Navigation: Low-frequency navigation signals degraded for brief intervals.	M1 (10^{-5})	2000 per cycle (950 days per cycle)

* Flux, measured in the 0.1-0.8 nm range, in $W \cdot m^{-2}$. Based on this measure, but other physical measures are also considered.

** Other frequencies may also be affected by these conditions.

Solar Observations: Irradiance (EXIS)



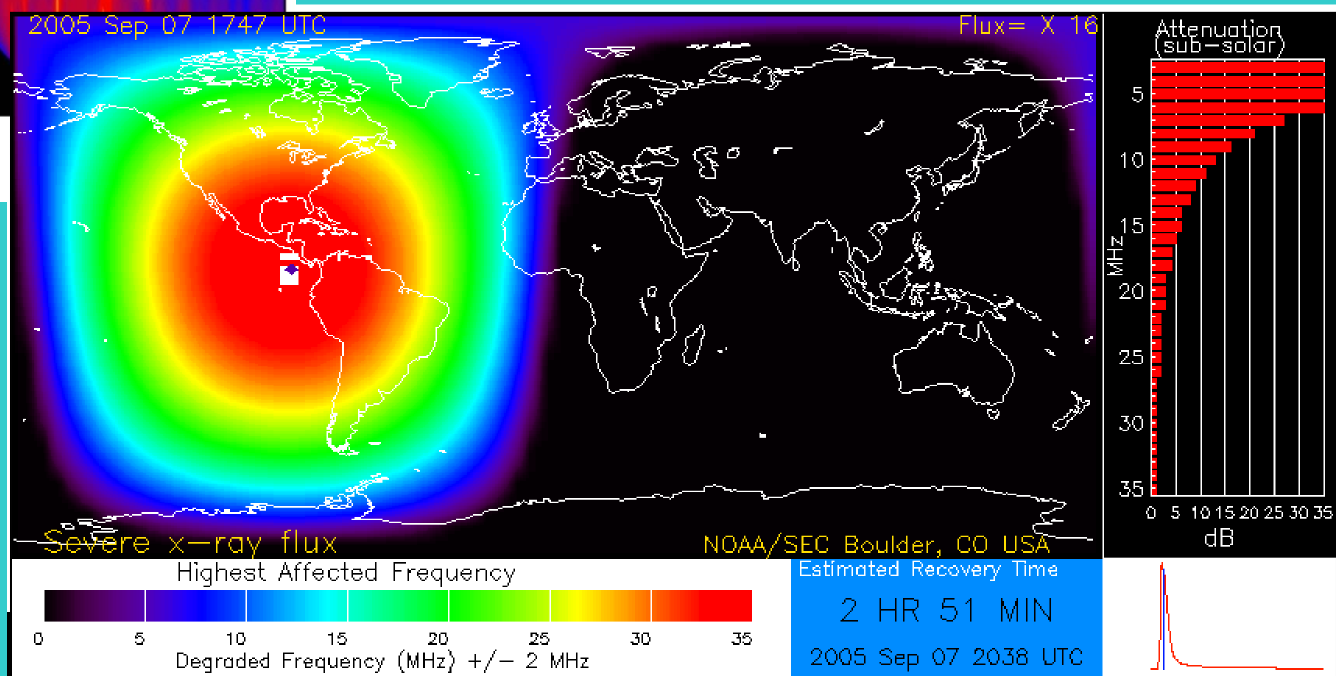
Extreme Ultraviolet and X-ray Irradiance Suite

EUV Sensor (EUVS)

Measures the solar EUV energy input to the upper atmosphere and improves the ability to predict upper atmospheric and ionospheric conditions.

X-Ray Sensor (XRS)

Monitors whole-Sun X-ray irradiance in two bands and drives the Radio Blackout portion of NOAA's Space Weather Scales.



XRS: Meeting Results and Questions

- Continuity of observations
  - Flare magnitudes remain constant
    - Does not require repeat of the current bands
- Irradiance Range
  - Need to include the lower values (quiet solar min)
- Spectral Band Shapes:
  - May not need to require specific band shapes.
    - …as long there is good correlation with current flare designations
- Are the bandpasses adequate for solar modeling?
- Is Geosynch the best place from which to make solar obs?

Viereck

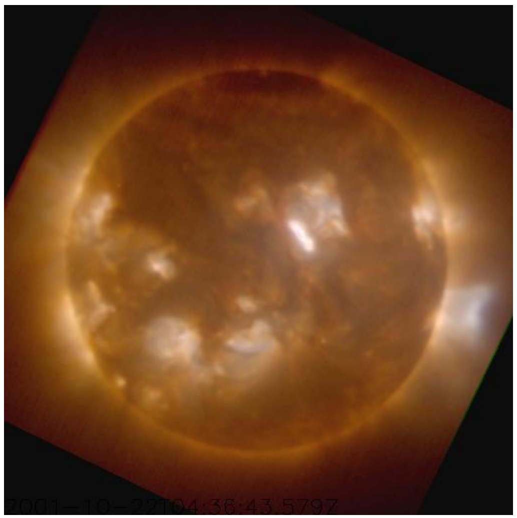
EUVS: Meeting Results and Questions

- Provide a measure of the solar EUV irradiance at Earth
  - Spectral resolved measure of energy into the ionosphere and thermosphere
- Continuity with current observations.
  - He 304, H Lyman Alpha (121nm)
- Need for interpretation of solar data for Ionosphere/Thermosphere modelers.
  - Can't just provide data
- What are the right resolution or number of lines or bands?
- Should the MgII observations become a requirement for future GOES?
- Should spectral dimming become a new requirement?
- What is the relative importance of accuracy, precision, stability, etc…?

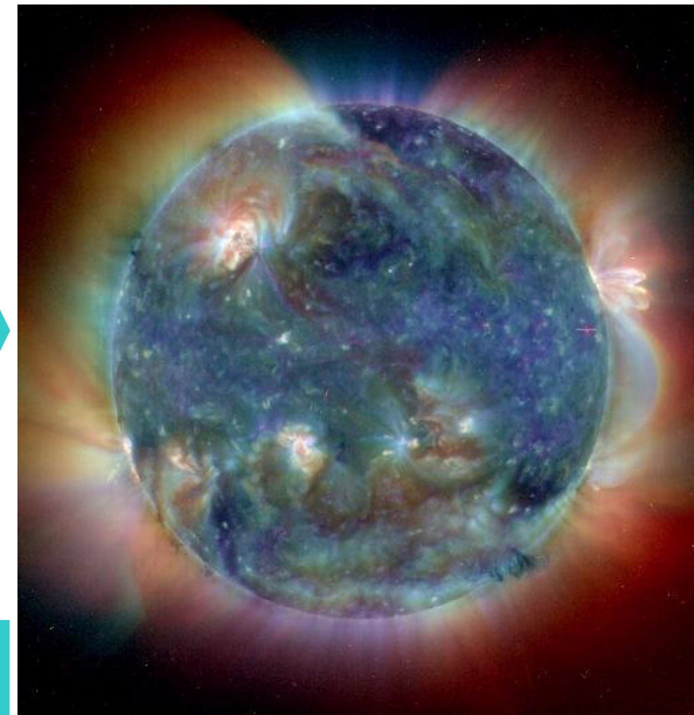
Viereck

Solar Observations: Imaging (SUVI) Solar Ultraviolet Imager

GOES-12 SXI color composite.



SUVI will image the same portions of the Sun's atmosphere as SXI, but in different spectral bands that provide better access to temperature and density.



Simulated GOES-R SUVI color composite (SOHO EIT data, a joint NASA/ESA research program).

SUVI will locate coronal holes, flares, and coronal mass ejection source regions. It will also detect "Over the horizon" active regions and observe active region complexity. Together, these observations support *all* space weather customers.

SUVI: Meeting Results and Questions

- **Solar imaging, broadly defined, is deeply entrenched in daily use by forecasters and models. Requirements need to be assessed across the broad array of needs.**
- **GOES R using the EUV imaging instead of SXR will result in a substantial benefit for forecasting.**
- **Magnetograms provide the only measure of magnetic complexity, polarity, etc. They also provide the sole basis for steady state solar wind models. The measurements can be made from the ground, with some limitations, e.g., seeing, cloud cover.**
- **The top unmet need is a dedicated CME imager for operations. L1 is the preferred location, but needs might be met with a GEO coronagraph if necessary.**
- **Use of imagery to initiate or validate models should be further refined and integrated across types of imagery, e.g., magnetograph coronal holes versus EUV coronal holes.**

Evolution of GOES Charged Particle Coverage

Satellite Series	Electrons 0.03-30 keV	Electrons 30-600 keV	Electrons >800 keV	Ions 0.03-30 keV	Protons 80-800 keV	Protons >740 keV	Heavy Ions, >10 MeV/n
GOES 8-12			√			√	He
GOES 13-15		√	√		√	√	He
GOES R-U	√	√ (gap 30-50 keV)	√	√	√	√	He, Z=4-29 (Be-Cu)
Space weather application	Frame charging, charging signatures	Frame and interior charging	Interior charging, radiation belt alerts	Frame charging signatures, ring current	Surface damage	SEP event alerts, surface damage	Single event effects

GOES 8-12

GOES 13-15

GOES R-U

Rodriguez

GOES Next Measurements

- Particles are a top priority for both anomaly resolution and satellite design
  - The primary hazards to satellites are caused by plasma and radiation particles
  - GOES-R adds energy resolution that permits maximum correlation between environmental measurements and satellite anomalies
- Magnetometer plays a critical supporting role:
  - Detecting magnetic reconfigurations
  - Mapping particle fluxes to other locations
  - Deeper scientific investigations (storm dynamics, wave-particle interactions)
- Example new measurement to consider: GPS occultation to detect plasmapause
  - Plasmapause marks boundary where surface charging is suppressed
  - Plasmapause marks boundary between different physical processes that modify global radiation environment

O'Brien

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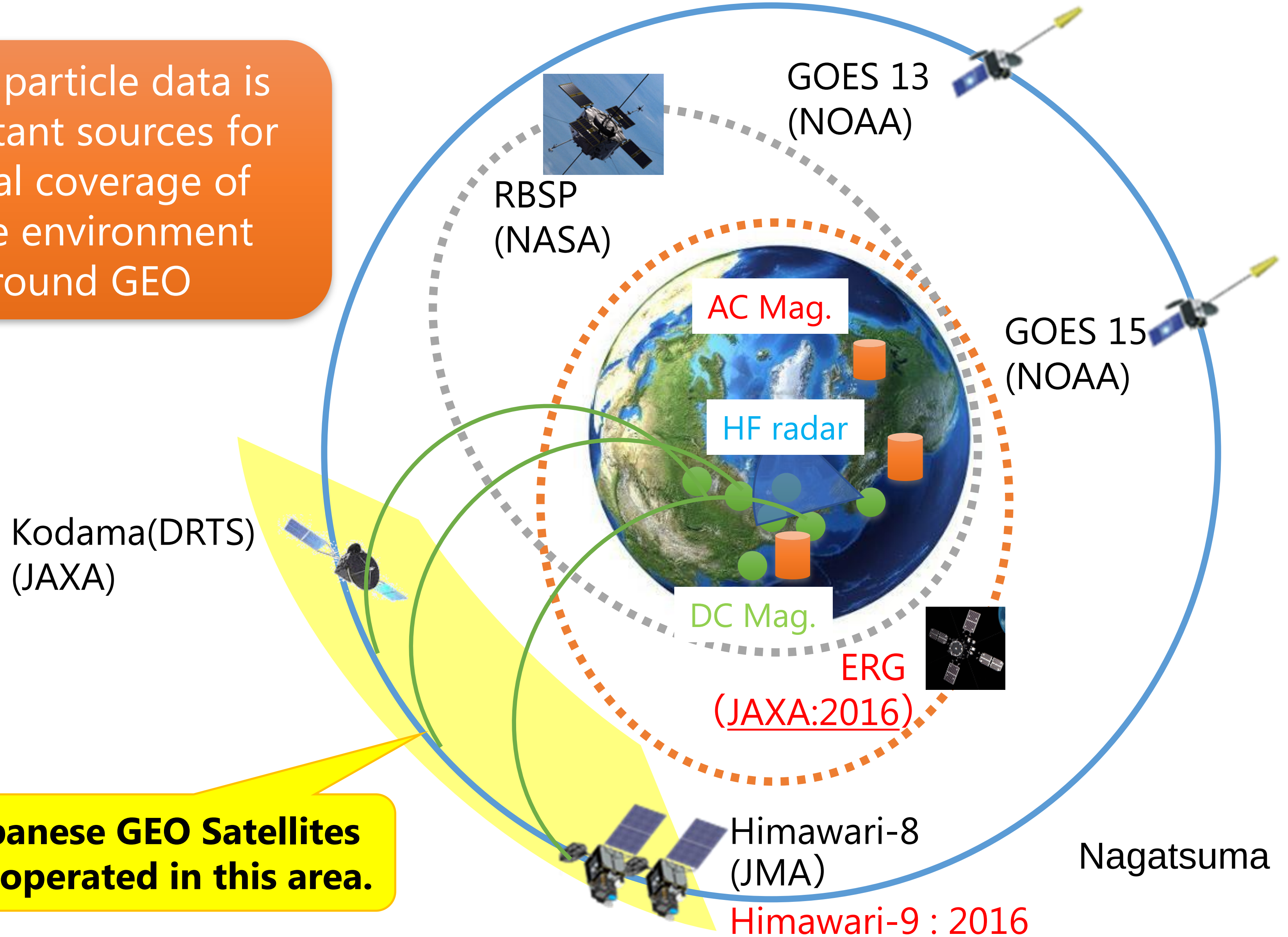
AEROSPACE

3-Dimensional Geospace Monitoring Network

GOES particle data is important sources for global coverage of space environment around GEO



Japanese GEO Satellites are operated in this area.

GOES Energetic Particles Summary Remarks

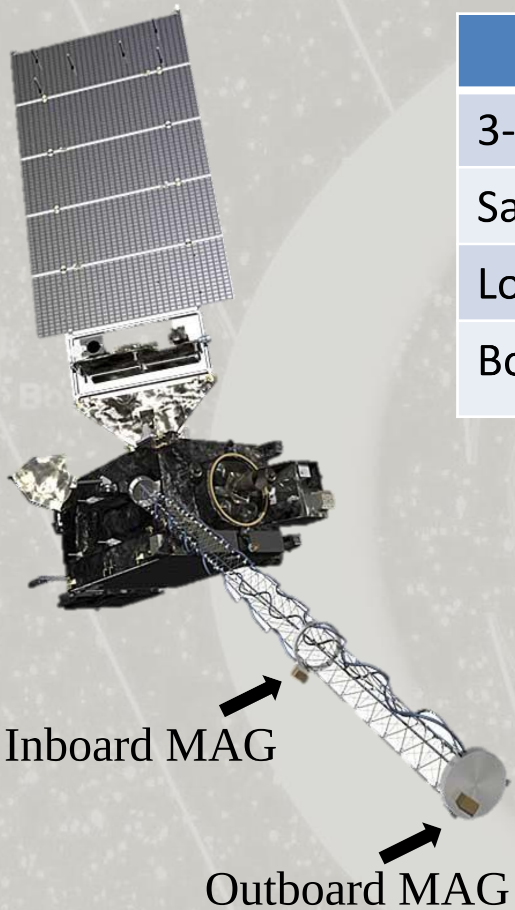
Kress and Rodriguez

- **Need for observations to support MEO satellites**
- **Importance of combining observations with models**
- **GOES-R observations fill a vital need—continue**
- **New, simple instrumentation to complement current instruments**
- **Fill gap between MPS Hi and Lo; importance of overlapping energy ranges for different instruments**
- **Ring current oxygen important for contamination**
- **Protons/heavy ions: SRAG needs high-energy tail of SEPs**
- **GOES needed for contribution to radiation protection in aviation; energy spectrum of solar particles needed for dose index and mitigation decisions**
- **GOES data needed for FAA Solar Radiation Alert System**
- **Eliminate proton contamination of high energy electrons**
- **Product cadence should improve from 5-min to 1-min**

GOES Magnetometer

Past, Current and Future

	GOES 8-12	GOES 13-15	GOES R-U
3-axis fluxgates	2*	2	2
Sampling Rate	2 Hz	2 Hz	10 Hz
Low-Pass Filter Cutoff	0.5 Hz	0.5 Hz	~2.5 Hz
Boom Length	3 m	8.5 m	8.5 m



GOES R-U magnetometer description and products:

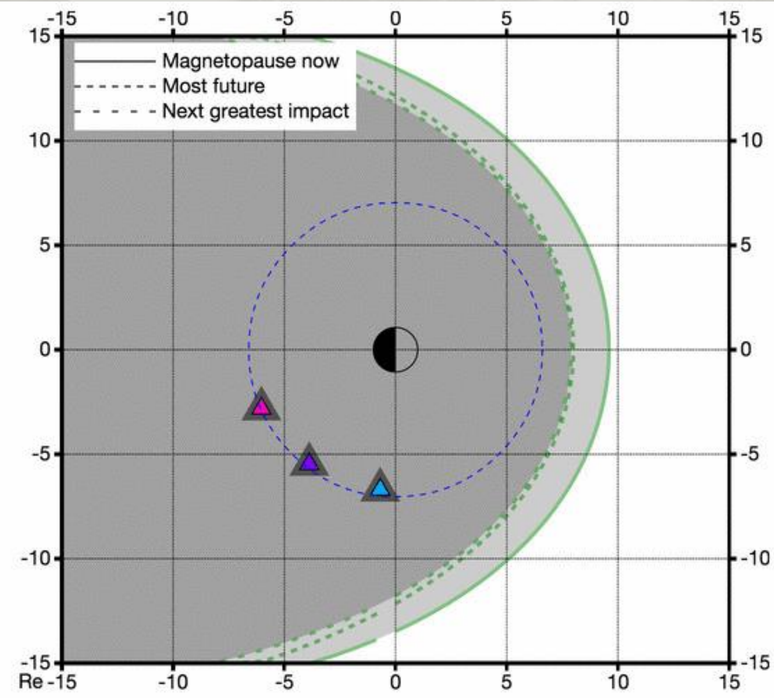
- 10 Hz samples with 3dB cutoff ~2.5 Hz
- Field vector in Several Coordinate Frames
  - 10 Hz: instrument, ECI, EPN, ACRF, BRF
  - 1-minute: instrument, ECI, EPN, GSE, GSM, VDH, BRF
- 1 minute averages
- Magnetopause crossing identification
- Comparison to Quiet Fields
- Support SEISS pitch angle determination

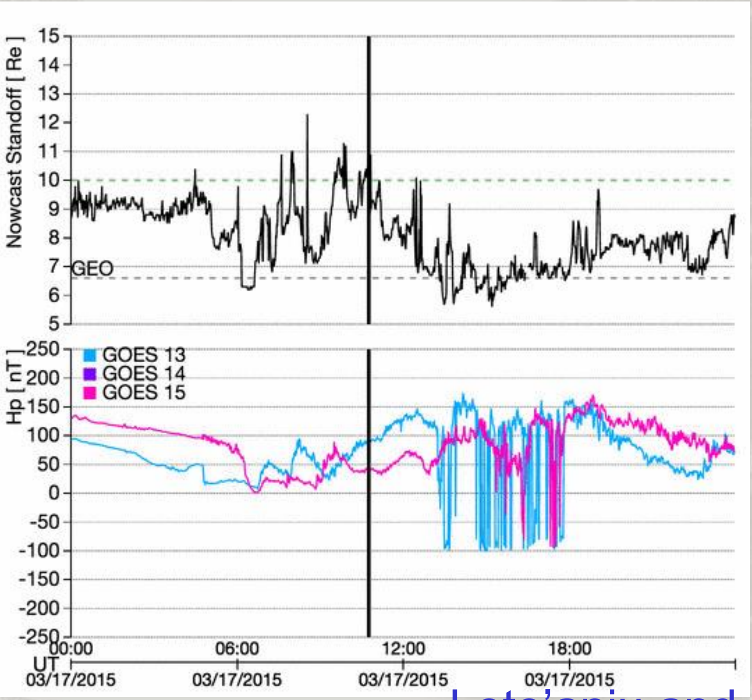
Redmon and Loto'aniu

GOES-R Magnetometer

Product Sample: Magnetopause Location

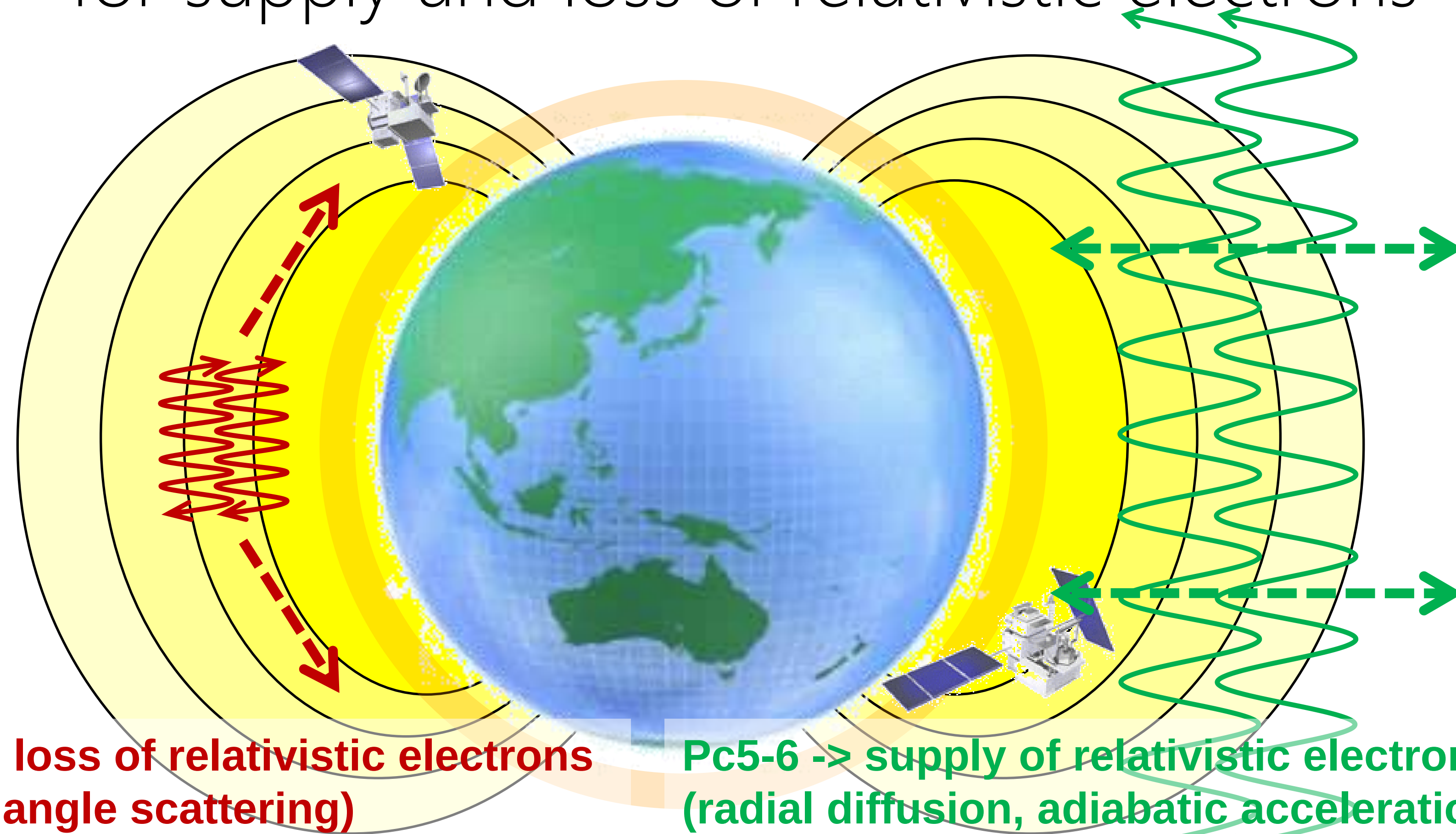
- Activity gauge - First indicator of substantial compression & erosion
  - Indicates elevated threat levels for space and ground based systems.
  - GEO satellites may find themselves inside in the magnetosheath.
- Development Funded by NOAA GOES-R Risk Reduction and Satellite Product and Services Review Board (SPSRB) Programs
  - Real-time GOES-NOP demonstration en route to NWS/SWPC Operations
  - http://www.ngdc.noaa.gov/stp/mag_pause/





Loto’aniu and Redmon

ULF-ELF waves plays an important role for supply and loss of relativistic electrons



Pc1 -> loss of relativistic electrons (pitch angle scattering)

Pc5-6 -> supply of relativistic electrons (radial diffusion, adiabatic acceleration, drift resonance acceleration)

If activity of EMIC waves around GEO can be monitored by GOES, it would be useful for research work and modeling. Magnetic field variations around 0.1-100 Hz can be monitored by induction magnetometer.

GOES Magnetic Field Summary Remarks

- Magnetic field measurements crucial for: interpreting energetic particle obs; mapping particles to other locations; model validation; model development; SEP and cosmic ray access; predicting substorms and satellite charging environment…
- Multipoint measurements using GOES satellites in storage or international assets discussed
- E-field measurement recommended for particle transport models
- Magnetopause crossing product has broad implications for what it tells about responses of the magnetosphere during these conditions that can affect the radiation belts, the ionosphere, etc.
- Higher frequency magnetic variations are important for controlling radiation belt particle acceleration and loss; however more work needs to be done translating recent scientific advances into useful products

Loto'aniu and Redmon

General Summary Remarks

- In 2002, SWPC held similar workshops to gather advice for space weather observations needed in the GOES-R era. Results of these workshops led to improvements on the GOES-R series (initiating in March 2016). Your input makes a difference.
- While we are working on this one component of U.S. Space Weather observations, it is important to recognize that there are other platforms and locations and that space weather is global. We benefit from partnerships and international collaborations.
- The commercial sector (and universities) build our satellites and instruments. We look forward to new opportunities for these partnerships in accomplishing national space weather goals.
- Finally, thanks for your participation and contributions to planning for supporting space weather customers with the next generations of geosynchronous (and possible other locations) space weather observations.